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Interim Report
June 1981



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FIBER OPTIC TRANSCEIVER DESIGN

The MITRE Corporation

G. L. Tenuta

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INTRODUCTION

This report covers activities on the fiber optic transceiver design program accomplished during the third quarter period under Project 6310.

The design activities performed during this period include:

- a. A thermally compensated laser transmitter stabilized without the use of optical feedback or thermoelectric cooling and featuring analog and digital provisions
- b. An LED (light emitting diode) digital transmitter employing an avalanche capability for low duty cycle or quasi-pulsed operations
- c. An ultra-high-gain, high sensitivity wide-band, 100-MHz transimpedance bipolar preamplifier
- d. An ultra-high-gain, capacitively neutralized, high-impedance FET (field effect transistor) preamplifier optimized for low bandwidth applications
- e. An ultra-high-gain, capacitively neutralized, bipolar high-impedance preamplifier incorporating an active equalizer for applications requiring low noise and high bandwidth
- f. A 100-dB general purpose AGC (automatic gain control) digital receiver featuring d.c. restoration, 50-MHz (nominal) bandwidth, and TTL logic compatibility
- g. A fixed-gain, limiting receiver incorporating a photodetector, preamp, postamp, and 50-ohm line driver or so-called all-in-one fiber optic receiver

Items "c" and "d" have been reported in a subsequent document, Fiber Optic Receiver Preamplifier Design, in preparation, and consequently will not be considered further herein. Remaining items represent activities accomplished during the current period and will therefore be treated exclusively in this report.

SELF-COMPENSATING LASER TRANSMITTER

Self-compensation is a technique employing thermal matching between a silicon transistor and a semiconductor laser to achieve open-loop compensation of laser temperature dependence. Normally optical feedback and thermoelectric cooling are employed to stabilize laser

temperature instabilities. However, thermoelectric cooling consumes considerable power and limits applications where lasers may be used (e.g., repeaters) while optical feedback introduces considerable complications requiring the addition of a photodetector, optical linkage to the laser, and added electronic hardware that increases cost and complicates the design. In addition, optical feedback for digital systems is generally different from that of analog systems, complicating the problem even further. The present design not only circumvents these problems, but is simple, effective, and compatible with both analog and digital system applications.

A schematic diagram of the self-compensated laser, configured for digital operations is depicted in figure 1. Figure 2 shows the associated board layout for the circuit.

Transistor Q_2 , which is the temperature sensing and compensating component, is mounted on the laser support and responds to changes in the junction temperature of the laser affecting d.c. bias and hence output optical power. An emitter resistor, consisting of two parallel 5-ohm resistors, is selected to match the temperature coefficient of the laser. The base-emitter voltage of Q_2 exhibits a nominal temperature coefficient of about 1.9 mV/°C and in conjunction with the selected emitter resistor provides an anticipated 80°C temperature range over which dynamic laser threshold control can be accomplished.

The temperature coefficient of Q_2 is exponential for moderate base voltage and follows a similar negative temperature coefficient exhibited by the laser, making thermal compensation of the laser a practical reality free from the other complications associated with conventional designs. In addition, because the coupling is thermal, the usual problems associated with bias control for digital systems, particularly the limiting all ONES or ZEROS case, are eliminated allowing equally effective performance for analog or digital operation.

A current source, consisting of transistors Q_3 and Q_4 , sets the modulation index of the laser drive circuitry, a Plessey differential pair, designated SL360C. The current source is temperature compensated (see figure 2) by placing each transistor in physical contact with the other. This is done to prevent temperature changes in the constant current source, which affect the laser modulation, thus preventing interference with the biasing of the laser.

For analog operation (figure 1), resistor R_1 is removed allowing the bias condition for the differential pair to be established by two 50-ohm base resistors associated with each transistor pair. Capacitor C_1 and R_3 , in this configuration, form a low-pass filter

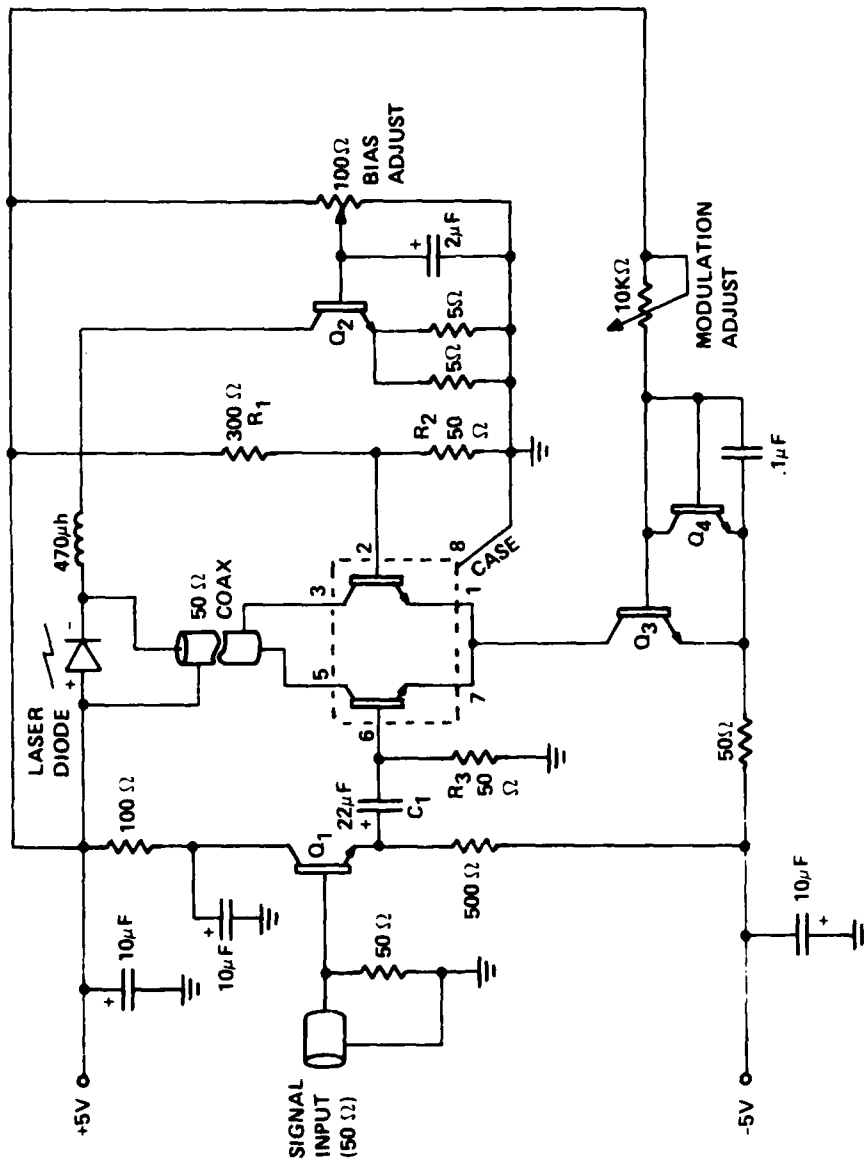


Figure 1. Self-Compensating Laser Transmitter

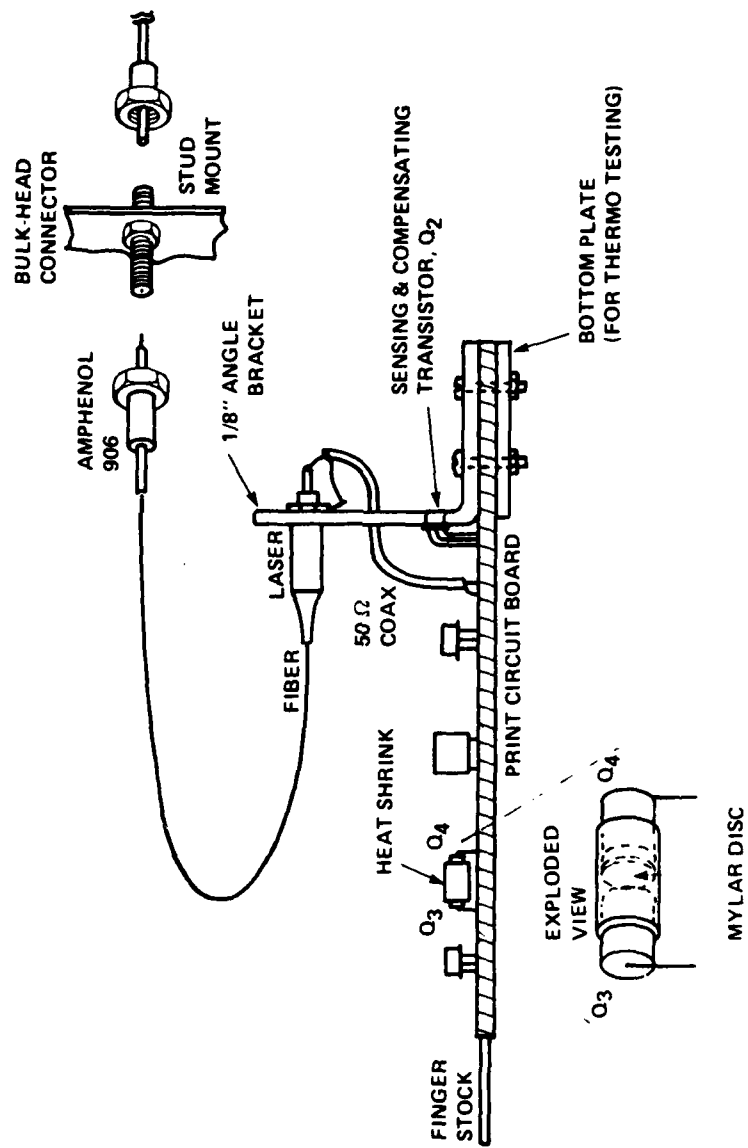


Figure 2. Board Layout For Self-Compensating Laser Transmitter

that sets the low frequency response of the transmitter. Removal of C_1 and replacement of R_1 by a 1500-ohm resistor and R_2 by a standard silicon diode IN914 extend the low frequency response to direct current, should this capability be required. However, care should be exercised that the 60- and 120-Hz frequency components, generated by the power supply, do not work their way into the optical output of the laser. Unless a very good power supply is used, one with good regulation and rejection at 60 Hz, this particular configuration is not recommended.

Digital operation uses the configuration shown in figure 1 except that capacitor C_1 is removed or shorted and resistor R_3 is removed, preventing conduction of current through the laser until the signal voltage, e.g., digital input signal, exceeds one diode drop, approximately 700 mV. Below this value, which corresponds to the noise margin of the receiver, or TTL logic, the laser remains in a nonconducting state. When the 700-mV threshold is exceeded, the differential pair, acting now as comparator as opposed to a linear amplifier (employed above for the analog case), causes the current through the laser to rapidly switch from full-off to full-on. The differential pair offers low input capacitance and provides very fast rise times in the optical output, considerably faster than the standard TTL input.

In order for the transmitter to perform properly, a sharp well-defined characteristic of the laser's P vs. I curve is required. The threshold current should be less than about 70 mA, the maximum compensation which can be accommodated by a single transistor compensating circuit, such as described herein.

AVALANCHING LED DIGITAL TRANSMITTER

An avalanching LED digital transmitter, designed to avalanche above a specified input voltage, is shown in figure 3. Although the transmitter has various applications, the present circuit was developed primarily for the 26-pair digital cable replacement program. In this application, sync pulses of 1 μ s duration are transmitted at a level considerably above the standard data pulses to enhance detection and the SNR (signal to noise) ratio at the receiver.

Modulation of the LED (figure 3) is accomplished using a high-speed differential pair configuration implemented with discrete transistors. Due to the bias arrangement provided by a silicon diode, the differential pair acts as a linear amplifier for signal levels between one and two diode drops. Within this range the input signal is amplified in direct proportion to its amplitude and then

applied to the LED which produces a corresponding amplified optical output signal. This is the normal manner of operation for data signals. Above two diode drops, corresponding to sync pulses, the differential pair avalanches producing a highly amplified optical signal resulting from conduction of an IN914 diode located in the emitter of the differential pair.

A current source sets the nominal current level for operation of the LED. The current source can be adjusted to handle most LED's in the range of 40 to 400 mA. In the avalanche mode, above two diode drops, the current applied to the LED is equal to full output of the current source plus any avalanching current drawn, through conduction, by the emitter diode of the first stage differential pair. The two silicon diodes in the collector circuit of the differential pair balance the nominal 1.6-V forward drop of the LED, ensuring similar switching characteristics of each transistor at high frequencies.

NEUTRALIZED BIPOLAR PREAMPLIFIER WITH EQUALIZER

In a continuing effort to realize the lowest noise/highest sensitivity optical receiver, a neutralized bipolar preamplifier employing an active equalizer has been developed as part of the overall design program (figure 4). A similar circuit, employing a dual-gate metal-oxide semiconductor field-effect transistor MOSFET without equalizer and having reduced bandwidth is discussed in a previously referenced report on receiver preamplifier design.

The present design extends the typically low bandwidth of the high-impedance preamplifier from a few hundred kilohertz to approximately 10 MHz with a responsivity of 25 mV/ μ W. As with all high-impedance designs gain may be traded against bandwidth considerably enabling design flexibility in tailoring the gain-bandwidth performance of the preamplifier.

Neutralization is provided by transistor Q_2 which acts to lower the input capacitance of the PIN photodetector and first-stage transistor Q_1 . Neutralization of the PIN detector is provided via capacitor C_1 . The input load impedance R_{in} , consisting of R_1 and R_L , determines the optical gain and noise figure of the preamplifier.

The input impedance R_{in} , consisting of the parallel combination of R_L and R (see figure 4), is modified by the equalizer to provide a lower value at higher frequencies, thus extending the bandwidth of the preamplifier. The bandwidth of the preamplifier reduces with frequency as a result of the RC time constant of the PIN and first-stage transistor Q_1 . At the 3-dB point, the equalizer is adjusted

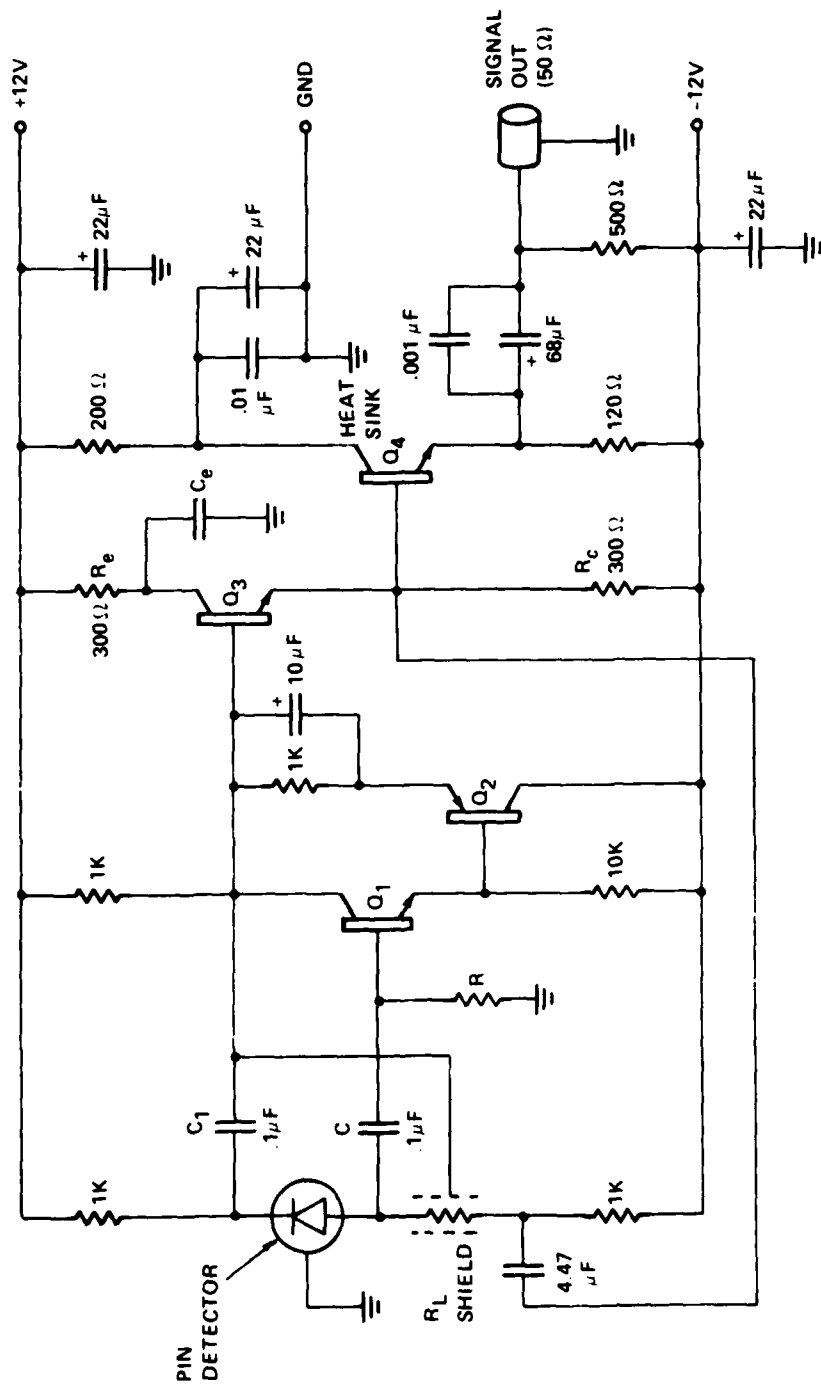


Figure 4. High Impedance Preamplifier Incorporating Neutralization and Equalization

via capacitor C_e and resistor R_e to compensate for the loss in gain by reducing the effective input impedance of the preamplifier. The exact relationship between parameters affecting the gain bandwidth product of the preamplifier is somewhat complex and not well-defined because of complex parameter relationships affecting the gain bandwidth product of the preamplifier. Nevertheless, analysis and measurement have suggested, for this specific case, that the best compromise between bandwidth, gain, and pass-band linearity can be obtained at R_L .

In the present design R_L and R are chosen to be 100 kilohms and C_e is experimentally found to be in the neighborhood of 700 pF assuming a Spectronics SD3322 PIN diode as the photodetector.

In general, naturalization is achieved through positive feedback while equalization, as used here, is obtained through negative feedback. Measurements have shown both techniques to be effective in extending the gain bandwidth product of the preamplifier. Measurements have also indicated an effective input capacitance of a few tenths of a picofarad, a value normally associated with hybrid designs. At this low value of capacitance it is possible to operate the PIN detector without any bias voltage up to a few megahertz. However, considerable efforts to achieve even lower capacitance using higher equalizer gains and other sophisticated techniques have proved unsuccessful, despite the overall success of the preamplifier as a low-noise/high-bandwidth optical transducer.

The noise output of the preamplifier was measured to be less than -80 dBm at 50 ohms corresponding to an extrapolated BER (bit error rate) of 10^{-9} at an estimated optical input level of 1 nW. For higher bandwidth applications, the reader is referred to a description of transimpedance amplifiers discussed in WP-22860.*

AGC DIGITAL RECEIVER

A digital receiver providing approximately 80 to 100 dB of AGC over an approximate 50-MHz bandwidth is shown in figure 5. As a general purpose receiver for digital applications the present design features single supply operation, e.g., +15 V, on-board regulation, direct circuit pulse restoration, and standard 50-ohm output

*G. L. Tenuta, "Electronic Circuits and Optical Sources for Fiber Optic Systems," WP-22860, Bedford, Mass.: The MITRE Corp., May 1980.

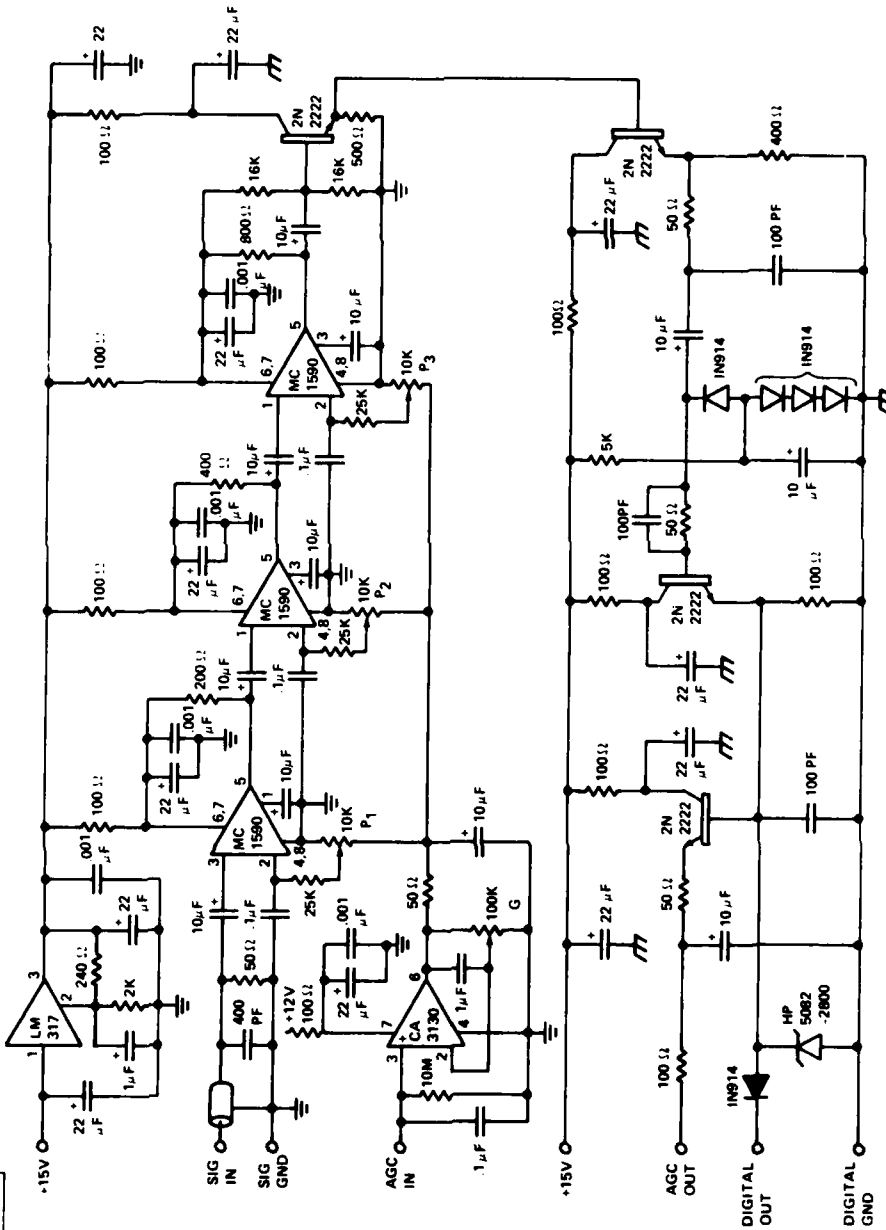


Figure 5. Digital Receiver With AGC and Direct Current Restoration

impedance for driving coaxial cable. The receiver is for use in a digital voice multiplexer system being developed for replacement of the Army's 26-pair cable. However, with the values shown, the receiver is not considered suitable for multi-terminal bus applications, since the AGC attack/release time is prohibitively slow. However, with minor modifications, involving simple resistor/capacitive changes, the receiver can be made to work equally well in this latter application.

The receiver operates in conjunction with an optical preamplifier, as implemented in this program. Because of the large receiver dynamic range capability, signals ranging between microvolts and millivolts may be easily accommodated. The output level of the receiver can be set over a relatively broad range of values, but 700 mV, peak-to-peak is considered fairly typical. Once set, the output will remain constant within a few percent for wide changes in input signal levels. Signals of higher or lower values having rise/fall times exceeding the attack/release time of the AGC circuit, e.g., about 1 ms, will be faithfully reproduced provided the maximum output level of the transistor driver, approximately 2.5 V, is not exceeded.

Three potentiometers associated with each of the three AGC amplifiers, P₁, P₂, P₃, provide adjustment for initiation of the AGC circuit. The series resistance, 25 kilohms, in each wiper arm of the potentiometers, provides gentle acting (e.g., low-gain) AGC characteristics enabling each amplifier to begin operation at approximately the same time when all potentiometers are fully bypassed. However, minor adjustments may be made to suit the user's specific requirements. For example, AGC amplifier 1 may be adjusted to begin operation first, followed by AGC amplifier 2, and then by AGC amplifier 3 in whatever order is considered appropriate for the user's application.

A remaining potentiometer, located in the feedback path of operational amplifier CA3130, G, is used to set the AGC level of the output stage, the voltage at which the output will be maintained.

ALL-IN-ONE LIMITING RECEIVER

An all-in-one receiver containing a PIN detector diode, preamplifier, postamplifier, and 50-ohm output driver is shown in figure 6. The receiver features a bandwidth of 6 MHz and a pin programmable output gain that can be set between 10 and 200 with the addition of a single resistor or short. The specific design objective here is to develop a miniature, self-contained receiver capable of analog FM operation. A prototype of this circuit has been developed and tested and found to meet all performance

requirements set for the initial design. The original board layout used in the demonstration model includes a few minor component modifications (additional) consisting of one to two resistors or capacitors, which have been placed on the back of the printed circuit board rather than revising the original circuit layout.

The design is relatively straightforward and takes advantage of commercial components for implementing all key circuit functions, primarily the photoelectrical conversion which relies on a Texas Instrument (TI) monolithic transimpedance preamplifier, part number TIEF 152.

The bandwidth of the TIEF 152 is stated as 20 MHz, but two other versions provided by TI enable operation to 50 or 100 MHz at correspondingly reduced gain. The transimpedance of the TIEF 152 is specified as 12 kilohms.

The photodetector uses an EG&G FND 100. The output of the detector is alternating current coupled to the preamplifier which presents an approximate 30-ohm input impedance, thus insuring good high-frequency operation.

The biasing circuitry of the detector, along with the coupling circuit to the preamplifier, sets the low-frequency response of the amplifier to about 1.5 kHz, enough to minimize the effects of low-frequency flicker noise at the input of the preamplifier.

Because of the high input impedance of the MC1590 (around 5 kilohms), the output of the TIEF 152 is loaded down by a 50-ohm resistor and capacitor. The capacitor aids in removing high-frequency noise, developed in later circuits located on the same board. Although the resistor-capacitor combination placed at the output of the TIEF 152 is not specifically recommended by the manufacturer, it is found experimentally to significantly reduce the noise level of the peamplifier.

An NE 592K (MC1733) equivalent is used as the final gain block for amplifying the signal and for driving a 50-ohm transistor driver circuit. Single-ended gains may be programmed, via pin options, to provide gains of 5, 50, or 200. Alternately, a resistor may be used to achieve intermediate gains ranging between 5 and 200. The present design employs a 3.3-kilohm resistor between pins 4 and 9 to provide a nominal gain of around 20.

Coupling capacitors placed between amplifier states including those in the detector biasing circuitry and output transistor driver serve to high-pass filter the signal removing the low-frequency components of the signals below approximately 1 kHz. Lowering the frequency

response down to around d.c. can be achieved by increasing all capacitors to about 10 μF . A value of 68 μF for the output transistor driver is considered more appropriate because of the normally low impedance presented by circuits which interface the preamplifier (e.g., nominally 50 ohms). This will markedly improve the low-frequency response of the preamplifier; however, the noise performance of the preamplifier would suffer somewhat. However, noise performance is not considered particularly significant for applications around 1 to 10 MHz where flicker noise is insignificant to other forms of receiver noise.



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